NASA Innovative Advanced Concepts

In-Space Manufacture of Storable Propellants

Completed Technology Project (2015 - 2016)

Project Introduction

Many deep-space, missions, especially those that return material or crews to near-Earth space, are severely limited by the need to carry propellants and heat shields to achieve their mission goals. Lifting these assets from the surface of Earth, landing them on the target body, launching them from there into an Earth-intercept trajectory, and capturing them into Earth orbit requires Earth launch of masses of propellant that increase exponentially with the mission's total delta V requirement. Preliminary studies of the logistics of gathering material from the Moon and selected Near-Earth Asteroids (NEAs) have demonstrated very large enhancements of mass-retrieval capabilities using propellants derived from sources in space rather than propellants launched from Earth and carried throughout the mission. They also have clearly shown the enormous advantages inherent in deriving propellants from NEAs. This study examines water-based propulsion using NEA volatiles to manufacture storable chemical propellants. The problem of storable propellants on Earth has been solved by the use of hydrazine derivatives as fuel and N2O4 as oxidizer, both made possible by Earth's nitrogen-rich atmosphere. Nitrogen is scarce on asteroids, and would be best devoted to creating fire-retardant atmospheres for crews. There are plausible paths known for making asteroid-derived carbon-based storable fuels, but the provenance of a suitable storable oxidizing agent that does not employ nitrogen is an unsolved and difficult problem.

Anticipated Benefits

Enormous improvement in mass-retrieval capabilities from asteroids and other bodies: mass payback of order 100:1 (retrieved payload/mass launched from LEO) instead of 0.1:1 or less for conventional Earth-based chemical propulsion. This is a true game-changer that opens the inner Solar System to efficient exploration and commercial exploitation, vastly increasing the mass of resources available to support human activities on Earth and in space.

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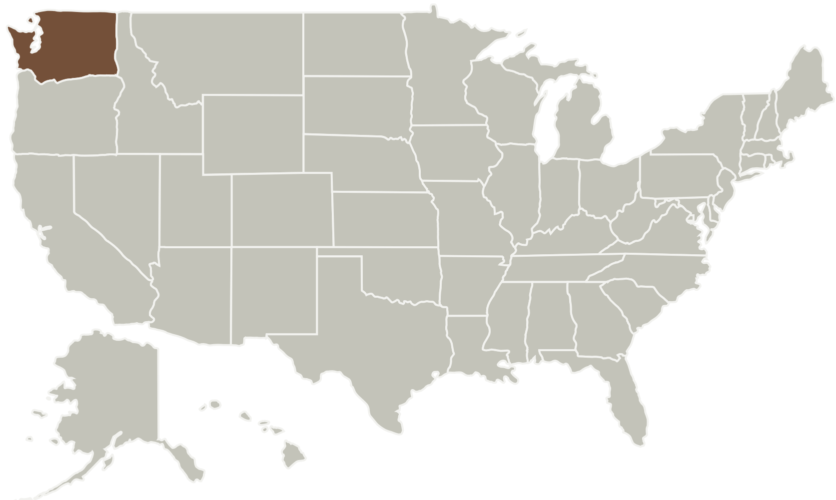
Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
Deep Space Industries, Inc.	Lead Organization	Industry	San Jose, California

Primary U.S. Work Locations
Washington

Project Transitions

July 2015: Project Start

Organizational Responsibility

Responsible Mission Directorate:

Space Technology Mission Directorate (STMD)

Lead Organization:

Deep Space Industries, Inc.

Responsible Program:

NASA Innovative Advanced Concepts

Project Management

Program Director:

Jason E Derleth

Program Manager:

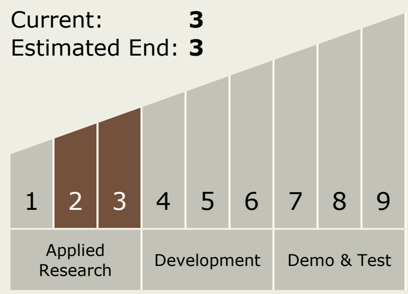
Eric A Eberly

Principal Investigator:

John R Lewis

Technology Maturity (TRL)

Start: **2**
Current: **3**
Estimated End: **3**



June 2016: Closed out

Closeout Summary: Our exploration of the feasibility of in-space production of storable propellants from resources available on asteroids, and also on Mars and the Moon, has considered the process of sample acquisition; the energy require ments for heating and volatile release; the thermodynamic behavior of gas relea se from minerals and organic polymers containing hydrogen, oxygen, carbon, su lfur, and nitrogen; purification of the released water and carbon dioxide; the sto rage and transportation of these materials in the condensed state; synthesis of f uels including methanol and dimethyl ether (DME); and the co-production, conc entration, stability, and storage of the complementary oxidizer high-test hydrog en peroxide (HTP). We call attention to the ability of the storable propellant/oxid izer combination of DME and HTP to carry out deep-space missions and to perfor m retrieval and relocation of any and all space-derived resources, such as retrie ving asteroidal metal to high Earth orbit. This study's analyses are based on retu rning resources to a storage/processing/dispensing facility in a Highly Eccentric Earth Orbit (HEEO) with a perigee above geosynchronous orbit and an apogee a pproach or beyond the Moon's orbit. The methane/LOX option, notable for good engine performance, has not been included in this study because our scope inclu des only fully storable propellants. This work in Phase I has led to a number of c onclusions. These are: 1. Thermodynamic theory shows that extraction of water and carbon dioxide from carbonaceous (C-type) near-Earth asteroids by means of direct solar heating is feasible and efficient. This is in agreement with experim ents carried out by Joel Sercel in an independent NIAC Phase I project, using bo th CM type meteorite material and a C-type asteroid simulant that we have deve loped at DSI and the University of Central Florida under an SBIR grant running c oncurrently with this (and his) NIAC grant. 2. The same theory also predicts that attempts at full extraction of volatiles from a C asteroid will require calciner tem peratures of at least 700 K, at which temperature not only does the native orga nic polymer in the C asteroid material react with magnetite (Fe3O4) to generate carbon dioxide and water vapor, but also these gases react with coexisting sulfid e and sulfate minerals to release copious amounts of sulfur dioxide. This predicti on has also been qualitatively verified by Joel Sercel's work on meteorite and DS I simulant materials. At these temperatures, release of H, C, O, N, and S produc es gases amounting to about 40% of the total mass of the asteroidal material.
3. The principal sulfur gas released, sulfur dioxide, is a source of some concern f or several reasons. It is a toxic and offensively odorous gas that must be remov ed from water intended for life-support or hydroponic use. It also spontaneously generates elemental sulfur and sulfuric acid, highly undesirable materials that ca n corrode or clog water-handling systems such as Solar Thermal Propulsion engi nes. Further, some of these sulfur compounds can poison the catalyst beds used in several critical processing steps in manufacture of propellants and metal prod ucts. 4. Sulfur impurities may be removed on the asteroid from freshly generate d impure water to make it safe and suitable for these uses. The application of Re verse Osmosis (RO) or other relevant technology provides the requisite purificati on in a simple and safe manner, using equipment of high TRL. The purified wate r is then suitable for use in everything from STP thrusters to chemical reagents t o chemical propellant manufacture to life-support fluids. (4alt.) Alternatively, SO 2 release may be minimized by using lower calcining temperatures, which also s everely limits CO2 release. This option suggests retrieval of only water to HEO o n the first mission, with production of only H/O propellants. Such a mission woul d also provide an opportunity for retrieval of unprocessed asteroid material to H EEO for use in process-development experiments there, relegating CO2 and SO2 production to HEEO. 5. The rejected sulfur compounds from water purification ar

Technology Areas

Primary:

- TX01 Propulsion Systems
  - └ TX01.1 Chemical Space Propulsion
    - └ TX01.1.2 Earth Storable

Target Destinations

The Sun, Earth, The Moon, Mars, Outside the Solar System

Project Website:

https://www.nasa.gov/directorates/spacetech/home/index.html